National Bureau of Standards

TECHNICAL NEWS BULLETIN

VOLUME 35 MAY 1951 NUMBER 5

An Air-Launched Automatic Weather Station

A self-contained automatic weather station, which transmits weather data by radio, has been developed by Percival D. Lowell and William Hakkarinen of the National Bureau of Standards for the Navy Bureau of Ships. Named the "Grasshopper", the device can be parachuted from aircraft onto inaccessible territory. Developed during World War II, it will automatically set itself up and periodically make and transmit weather observations. It may also be used as a radio marker beacon.

After the station has parachuted to earth, controlled explosive charges are used to disengage the parachute, raise the station to an upright operating position, and erect a telescoping antenna. Weather-responsive devices then cause resistance changes that switch a radio transmitter on and off at a rate susceptible of translation by a receiving station into temperature, pressure, and humidity readings.

Designed in the shape of a bomb, and packing its own parachute, the weather station is loaded on the bomb rack of an aircraft. When the unit is released over a desired location, the parachute is automatically opened by a line rigged from the aircraft. Simultaneously, an electric clock, which controls subsequent operations of the station, is turned on. The impact of landing sets off a small explosive charge that disengages the parachute and prevents the station from being pulled along the ground. Either immediately or after a preset dormancy period, another explosive charge causes the station to rise to an upright operating position. This is done through an arrangement of six legs to which springs are attached; the explosive charge operates a release, permitting the springs to pull the legs into position. A third explosive charge extends a telescopic vertical antenna to a height of some 20 feet. The station is then ready for automatic transmission at intervals predetermined by the built-in timing mechanism.

The automatic station could be adapted to transmit various kinds of information; but in the standard design only temperature, pressure, and humidity data are reported. Separate mechanisms responsive to changes in these atmospheric conditions each cause an associated resistor to vary. At predetermined intervals the timing mechanism turns on the radio transmitter and connects one resistor after another to a critical point in the transmitter circuit. The transmitter is designed so that the emitted radio signal pulses on and off at a rate proportional to the value of the resistor so connected. The station is calibrated before use by subjecting it to known temperatures, pressures, and humidities, and measuring the resulting pulse rates. At the receiving station the transmitter pulse rate can then be read as temperature, pressure, or humidity, depending on the phase of the predetermined clockwork cycle.

The radio transmitter proper consists of a crystal oscillator followed by a radio-frequency amplifier stage. A relay in the plate circuit of a separate relaxation oscillator turns the crystal oscillator on and off at a rate proportional to the value of whatever resistor is tem-

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porarily inserted (by the clock mechanism) into the relaxation oscillator circuit.

The clock, in addition to inserting the several weather-responsive resistors into the circuit in a predetermined sequence, connects two other resistors at appropriate intervals. These are a reference resistor and an identification resistor, both of constant value. The pulse rate produced by the fixed reference resistor is observed during initial tests of the transmitter. Any subsequent deviation in this reference pulse rate warns the receiving station that a correction must be applied to the pulse rates of the weather-responsive resistors. Such deviation could arise from transmitter damage or aging.

The identification resistor is of a value selected to produce a pulse rate characteristic of the particular station. This enables the operator at the receiving station to identify the sending station.

A special technique is used to insure maximum accuracy of the transmitted data despite possible deformation of the weather-responsive mechanisms due to landing impact: a buzzer vibrates each weather-responsive device for a short time before its associated resistor is inserted in the relaxation oscillator circuit. The forced vibration counteracts friction, which may have been increased by landing-impact deformation; this aids in the attainment of a true equilibrium condition.

When the station is to be used as a beacon, the radio transmitter and its control mechanisms may be simplified so as to transmit a constant or intermittent signal only.

TECHNICAL NEWS BULLETIN

U. S. Department of Commerce

Charles Sawyer, *Secretary*

National Bureau of Standards
E. U. Condon, *Director*

MAY 1951 Issued Monthly Vol. 35, No. 5

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Subscription price, domestic, $1.00 a year; foreign, $1.35; single copy, 10 cents. The printing of this publication has been approved by the Director of the Bureau of the Budget, February 3, 1950.

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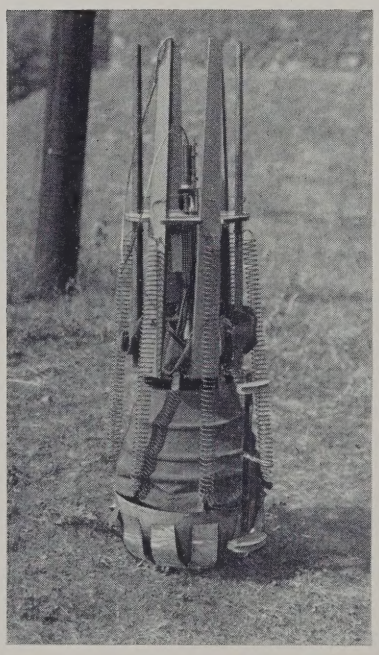
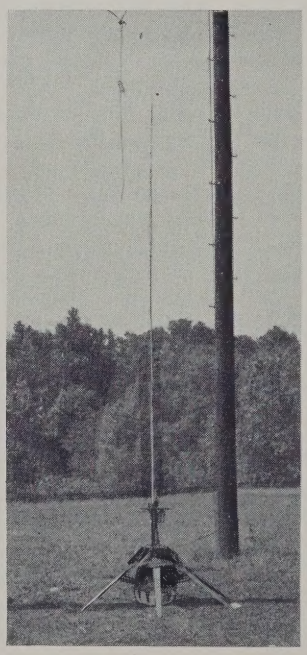
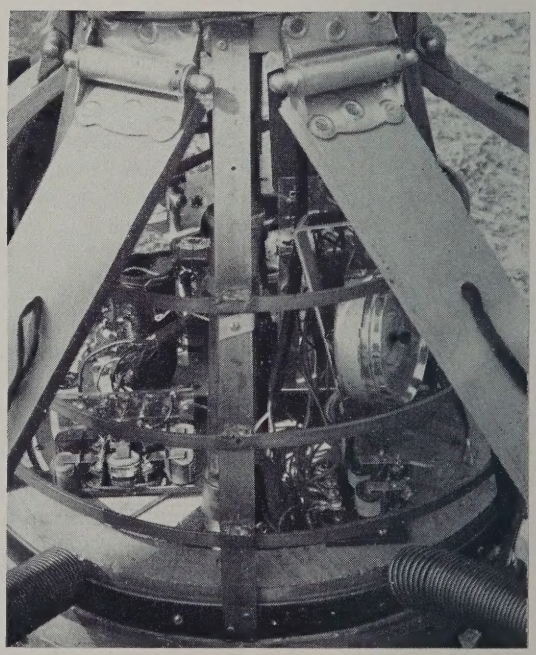






Experimental model of the air-launched automatic weather station (left) after explosive charge has released parachute. Two more charges release the spring activated legs (center), thus bringing the station into operating position, and raise the 20-foot antenna. Closeup (right) shows arrangement of components. The station transmits pulses that can be translated by the receiving station into temperature, pressure, or humidity, depending on the phase of a predetermined clockwork cycle.

The developmental model had an output of the order of 5 watts. Operating on a frequency in the neighborhood of 5 megacycles, it performed reliably over land at ranges of more than 100 miles. Dry batteries provided power for transmission of weather reports at 3-hour intervals for more than 15 days.

An Investigation of Battery Additives

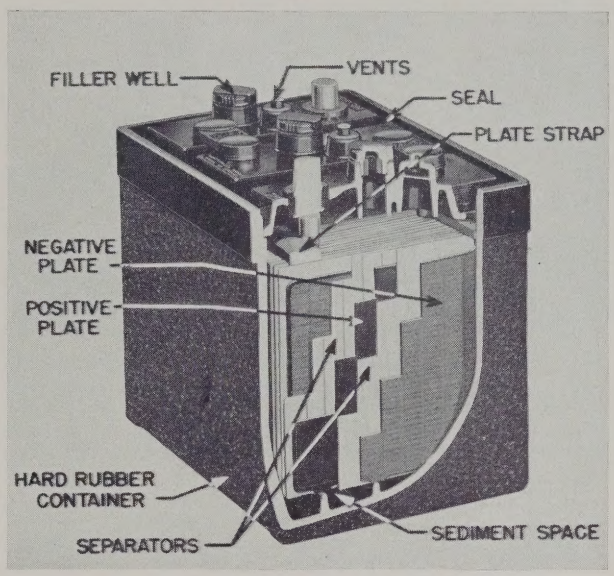
Recent investigations by P. L. Howard and G. W. Vinal of the Bureau's electrochemistry laboratory have shown that battery additives—preparations frequently sold with claims that they will rejuvenate "dead" batteries—in fact have no effect on battery life or performance. Extensive laboratory tests simulating actual service conditions were made on a wide variety of commercial additives. The results show no significant difference between the batteries treated with these mixtures and similar untreated batteries used as controls.

During the last 30 years, more than 100 different battery additives, both powders and solutions, have appeared on the market. Most of the solutions have consisted of sulfuric acid, sometimes with additions of sodium sulfate, magnesium sulfate, or coloring matter. In connection with a broad program of research on the properties of batteries, the Bureau investigated the liquid preparations several years ago and found that they produced no essential difference in the charging, voltage, efficiency, or operating temperature of a battery. Today, however, most of the common additives consist of combinations of magnesium and sodium sulfates in various states of hydration. The present investigation was therefore concentrated on these substances as representative of the powdered additives.

In general, the directions for using the additives specify that each cell of the battery be treated with the contents of the package, filled with water, and charged by means of the automobile generator for a certain length of time. A test is usually specified in which the starter motor drains the battery until it will no longer turn the motor; then, after a rest period, the ignition is turned on, and the starter will usually turn the motor over long enough to start it. Although untreated batteries can be expected to react in the same way to such a test, the purchaser is likely to believe that an improvement has been caused by the additive.

Obviously, a more objective method for determining the effect of the additives on battery performance was required. The Bureau therefore developed a series of simulated service tests designed to cover the principal characteristics of a battery and the claims most often made for the additives. To establish a valid basis of comparison between the treated and untreated batteries, a complete check was made on the characteristics of the batteries studied both before and after treatment.

Five 3-cell batteries of the Army 6-volt type 2H that had stood for 4 years in a charged and damp condition were filled with sulfuric acid of specific gravity 1.050 and given a 388 amp-hr charge. The batteries were in sound mechanical condition but, as a result of the deposition of lead sulfate on their plates, their initial capacities after prolonged charging were only about two-thirds of their rated capacity. After measurement

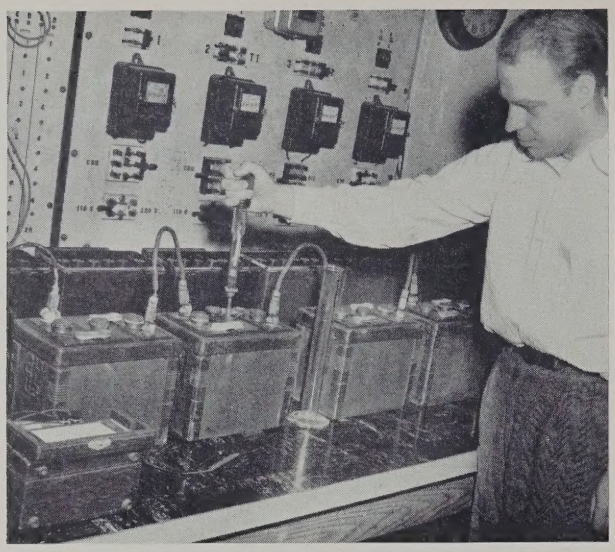


Cutaway view of an ordinary automobile battery showing major components. Each cell contains positive and negative plates separated by wooden or microporous separators. The positive plates are composed of a lead-alloy grid containing lead dioxide, while the negative plates are grids containing spongy lead. The electrolyte is a water-solution of sulfuric acid.

of capacity and stand loss, a series of combinations of magnesium and sodium sulfates were made up from representative commercial additives, and these combinations were added separately to various test cells of the group of batteries. Two cells in each battery were treated with the sulfates, while the third was untreated and used as a reference.

In practically every case, after treatment with the additives the capacity of the treated cells at the normal discharge rate decreased more than that of the control cell. This definitely shows that the use of such preparations does not improve cell performance nor does it remove sulfate from the plates, as has been claimed. If sulfate had been removed from the plates, there would have been a marked increase in the capacity of the treated cells. However, there was actually no real difference between the capacities of the treated and untreated cells.

Tests were also made to determine the effect of the additives on local action as indicated by changes in specific gravity during standing. The batteries were kept on open circuit for 3- and 4-day periods both before and after treatment. Specific gravity readings taken during these periods showed that the additives caused no reduction in local action.



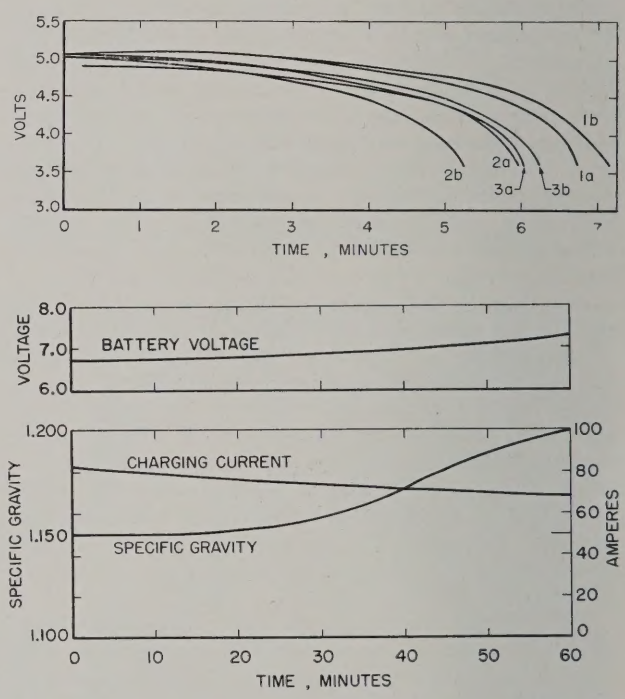
Automotive (front row) and aircraft (back row) batteries were studied to determine the effect of magnesium and sodium sulfate additives on their performance and useful life. Measurements of specific gravity showed no significant difference between treated and untreated cells.

Exponents of the solid type of additives usually claim that use of their products results in lower operating temperature and therefore reduced water consumption. This is based on the assumption that the additives will cause a reduction in the lead sulfate deposit on the plates. To investigate this point, the Bureau measured final cell temperatures at the end of a charging period both before and after treatment with the additives. Water consumption was also determined for treated and untreated cells over a 6-month period. In this test also, no significant differences were observed between the treated and untreated cells.

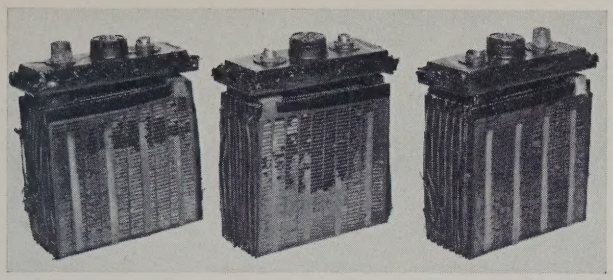
To determine the validity of the test suggested by the additive proponents, in which the treated battery appears to be rejuvenated on standing, the Bureau observed the voltages of both treated and untreated cells when subjected to a short high-rate discharge followed by a rest period. Unused batteries whose plates were sulfated from long, wet, shelf storage were charged and then subjected to a 300 amp constant-current load for 1 or 2 minutes followed by a 15-minute rest period on open circuit. Here again, no significant differences were found between the treated and untreated cells. In other words, repeated high-rate discharges after intervals of rest are normal to a storage battery and do not result from use of an additive. Statements made to the effect that use of additives will make lights brighter and the spark hotter are also misleading, as the voltage and current furnished the lights and ignition system come primarily from the generator rather than the battery while the car is in operation. Thus the lights will become brighter at high engine speeds and after the car has been running a while, even though the battery is not fully charged.

Use of an additive may sometimes appear to revive a battery that seems to be dead but actually is not. Often a battery that does not give a satisfactory reading with a hydrometer after a 30-minute high-rate charge is considered incapable of taking a charge. However, hydrometer readings do not give a true picture of the condition of the battery during the initial stages of charging. The sulfuric acid produced in the charging process, because of its greater density, tends at first to settle in the bottom of the cell, where it is not detected by the hydrometer. It is only after considerable gas has been evolved in the charging process that the electrolyte is stirred to the point where it is of uniform density and can give a fair test with a hydrometer. Likewise, the cell voltage does not change appreciably until near the end of charge.

To investigate further the possible effect of additives on self discharge, studies of local action were made on negative plates taken from a discarded battery. The plates were charged against pure-lead positives in sulfuric acid of specific gravity 1.050. After charge they



(Top) Capacities (at the 5-minute discharge rate) of stored batteries after various reservicing treatments. After a year in storage, the batteries were filled with sulfuric acid and divided into groups. One group (2b) was treated with a magnesium and sodium sulfate preparation, another with a saturated solution of sodium sulfate (3a), and a third with a saturated solution of magnesium sulfate (3b). An additional group (2a) was treated with the commercial sulfate preparation before storage, and two groups (1a, 1b) were left untreated as controls. The bottom two graphs show the fallacy of judging a battery by its measured specific gravity and voltage after a quick charge. Note that both specific gravity and battery voltage remain low during the first 35 minutes of charging. Charging current, on the other hand, decreases at a constant rate.



Cell groups from a standard automotive battery at the end of its useful life. The positive plates (left edge of each cell) are corroded, and the outer grid frame is ruptured. Similarly, the negative plates (front of each cell) have lost some of their active material and are badly sulfated.

were placed horizontally in tanks of sulfuric acid of specific gravity 1.350, and glass tubes closed at one end were placed over portions of the plates to collect the gas given off in a 24-hour period. Then the plates were taken out and recharged in sulfuric acid of specific gravity 1.275 treated with the various mixtures of magnesium and sodium sulfates, and the test was repeated. Local action, as indicated by the amount of gas collected, was not reduced by treatment with the additives.

In another series of tests, batteries were stored dry for 1 year and then reserviced with different electrolytes. Some were filled with a standard battery solution consisting of sulfuric acid of specific gravity 1.280. Others were filled with acid to which had been added either (1) a commercial preparation of magnesium and sodium sulfate, or (2) a saturated water solution of sodium sulfate, or (3) a saturated water solution of magnesium sulfate. Capacities were measured at the 5-minute and 5-hour discharge rate. In every instance the standard procedure of filling with acid resulted in higher capacities than did the use of combinations of magnesium and sodium sulfate with the acid.

The Bureau's laboratory tests were confirmed by field tests carried out independently over a 6-month period by the Ordnance Corps, Department of the Army, on 200 automotive batteries at ordnance depots throughout the country. Two-thirds of the batteries were treated with a mixture of sodium and magnesium sulfate, while the remaining third were tested as controls. The condition of the batteries was checked each month, and at the end of the 6 months the percentage variation in specific gravity and the number of satisfactory batteries in each group were determined. As in the Bureau's studies, the results of these tests showed no benefit from use of the additives.

Average results of the NBS tests on Army 6-volt batteries

	Untreated cells	Treated cells
Capacity rating	120 amp-hr	120 amp-hr.
Initial capacity, all cells	64 amp-hr	
Initial capacity of treated cells:		
Before treatment	54 amp-hr	
After treatment		48 amp-hr.
Final capacity after 6 months:		
Untreated cells	13 amp-hr	
Treated cells		14 amp-hr.
Voltage at 1 minute, per cell, 300-amp load	1.45 v	1.12 v.
Recuperative voltage per cell, 1-minute after 300-amp load.	2.04 v	2.03 v.
Water consumption during 27-week test, per cell.	58 ml/week	59 ml/week.
Decrease in specific gravity during 4-day stand.	0.006	0.007.
Points lost at full charge during cycle test, 26 weeks.	0.020	0.028.
Cell temperature at end of eighth charge	39.0° C	38.4° C.

For further technical details, see National Bureau of Standards Circular 504, Battery additives, by Paul L. Howard and George W. Vinal, available from the U. S. Government Printing Office at 15 cents a copy.

Static Friction Tests With Special Lubricants

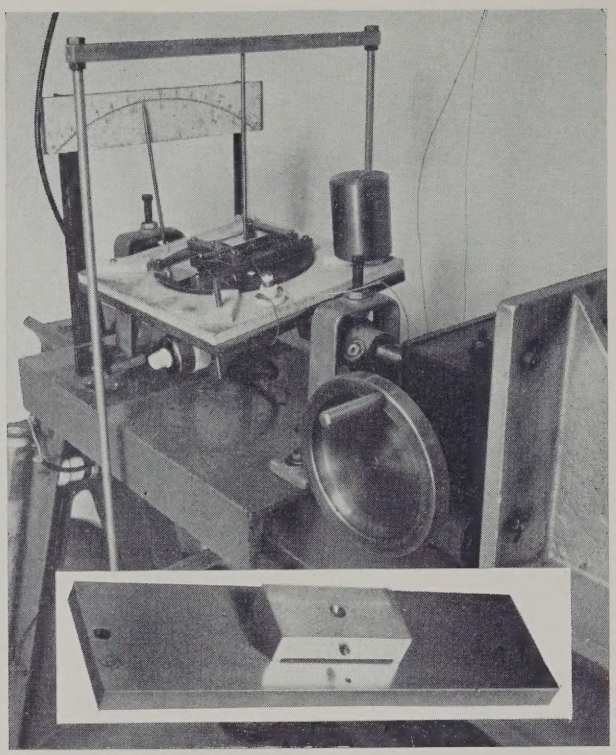
Static friction tests of a number of relatively new special lubricants, in combination with various metals, have recently been completed at the National Bureau of Standards. Selection of a lubricant for a particular special application was the immediate goal of the investigations, which were sponsored by the Naval Ordnance Laboratory and conducted by H. S. White of the NBS engines and lubrication laboratory. Although lubricant information was the primary concern of the tests, the effect of metal composition and of metal surface finish on static friction was also investigated.

Static friction coefficients are indices of the ease with which one of a pair of metal surfaces (lubricated, in the present case) will start to slide in relation to the opposing surface. While low static friction is desirable in many applications, it cannot be taken as an indication of over-all lubricant merit.

Some 20 special lubricants, principally chlorinated and fluorinated hydrocarbons with and without various additives, were tested. Additives included graphite, molybdenum disulfide, zinc oxide, boron nitride, and an oxidized petroleum compound. An SAE 10 mineral lubricating oil (Navy symbol 2110) was used as a reference or basis of comparison. Metal surfaces used in various combinations for the tests were stainless steel, carbon steel, cast iron, aluminum alloy, and chromium plate. An inclined-plane test apparatus of conventional design was used.

In the test method employed, a metal rider rests on a larger flat lubricant-coated metal plate. In the Bureau tests a load of 40 pounds per square inch was used, and a temperature of 100° F was maintained. The plate, initially horizontal, is slowly tilted until the rider starts to slide. The sliding of the rider is indicated electrically; a small motion of the rider closes a low-voltage circuit and lights a lamp. The tangent of the angle of tilt at which sliding begins is the coefficient of friction. This follows from the definition of the coefficient of friction, f, which is defined as F/W, where F is the tangential force required to initiate sliding, and W is the force normal to the surface.

Lowest static friction was shown, in general, by test



Apparatus for making static friction tests with special lubricants. A flat lubricant-coated metal plate rests on the table with a smaller metal rider on top. The table is slowly tilted as a pointer indicates the angle. The tangent of the angle at which sliding occurs is the coefficient of friction. A specimen rider and plate are shown in the insert.

lubricants containing molybdenum disulfide—closely followed by a mineral lubricating grease, dry molybdenum disulfide, and a fluorinated hydrocarbon with graphite additive. Lubricants for which the most favorable data were obtained showed static friction about 50 to 60 percent less than the SAE 10 reference oil. A lubricant containing an oxidized petroleum compound, and one containing a silicone grease, gave slightly less friction than the SAE 10 oil. Higher friction than the reference oil was shown by the chlorinated and fluorinated lubricants without additives, and by the remaining special lubricants.

Some of the metal combinations ranked about the same in friction, relative to other metal combinations, regardless of the lubricant with which they were tested. In the case of certain metal combinations, on the other hand, the relative rank of the combination depended to a much greater extent on the lubricant used.

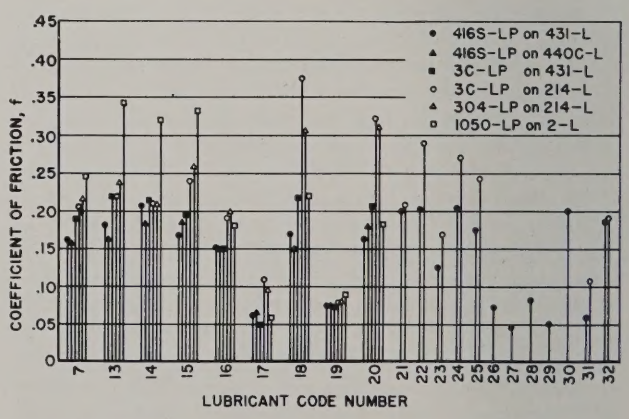
Certain heat-treated stainless-steel combinations showed, with most lubricants, the lowest friction values. With a few lubricants, a chromium-plated rider on a heat-treated stainless-steel plate gave low friction values comparable to those for the stainless-steel combinations. Dependence of relative friction rank on the lubricant was especially great in the case of an Alcoa 214 plate used with either a chromium-plated rider or a stainless-steel rider, and also for the combination of a 1050 steel rider and a cast-iron plate; each of these combinations ranked high in friction when used with one or more lubricants but low when tested with other lubricants.

Lubricants used in static friction tests

Code No.	Lubricant
7	Navy symbol 2110 oil (SAE 10)
13	Chlorinated hydrocarbon.
14	Organic phosphate ester.
15	Fluorinated hydrocarbon S (medium viscosity).
16	Fluorinated hydrocarbon S+1% oxidized petroleum compound.
17	Fluorinated hydrocarbon S+1% molybdenum disulfide.
18	Fluorinated hydrocarbon FS (light viscosity).
19	Fluorinated hydrocarbon S+1% graphite.
20	Perfluorokerosene.
21	Fluorinated hydrocarbon FS+0.5% copper phthalocyanine.
22	Silicone DC–200 (100 centistokes at 25° C).
23	Fluorinated hydrocarbon FS+2% silicone grease DC–44 (medium).
24	Fluorinated hydrocarbon KEL–F.
25	Fluorinated hydrocarbon FS+5% fluorinated grease (light).
26	Grease G (23.5% sodium soap).
27	Grease G+5% molybdenum disulfide.
28	Molybdenum disulfide (dry).
29	2110 oil + 1% molybdenum disulfide.
30	Fluorinated hydrocarbon FS+1% zinc oxide.
31	Fluorinated hydrocarbon S+2% molybdenum disulfide concentrate.
32	Fluorinated hydrocarbon S+0.75% boron nitride (amorphous).

Polished surfaces sliding on lapped surfaces tended to give lower friction and less variation than ground surfaces sliding on ground surfaces. Lapped plates and lapped-and-polished riders were used in most of the tests. Lapped and polished surfaces are more easily reproduced, and are more commonly used for machine parts involving small clearances.

For each metal rider-and-plate combination, tests were run alternately with the reference oil and with a number of the special lubricants. First, a series of observations was made using the reference oil. This was followed by a set of observations with one of the special lubricants. Then a second run with the reference oil was made, followed by another of the special



Graphic summary of static-friction tests. Lubricants are identified by code numbers (table). The height of each bar—for the particular metal combination as indicated by the symbols—represents the average coefficient of friction. Various lapped-and-polished (LP) metal riders were used in combination with lapped (L) metal plates.

lubricants, and so forth. After each set of observations with a particular lubricant the plate and rider were very carefully scrubbed and rinsed, using absorbent cotton and a number of solvents. This was done to insure that residual contamination from one lubricant should not affect results obtained with subsequent lubricants. The repeated sets of observations with the reference oil served by their consistency to confirm the reliability of the special lubricant data; this use of the reference oil showed both that the cleaning process was adequate and that test conditions had not been accidentally altered.

For further technical details, see Static friction tests with various metal combinations and special lubricants. Hobart S. White and Dino Zei, J. Research NBS **46,** *292 (1951) RP2198.*

Optical Society of America Honors NBS

Over 500 scientists attended the 3-day winter meeting of the Optical Society of America in Washington, D. C., on March 1, 2, and 3, 1951.

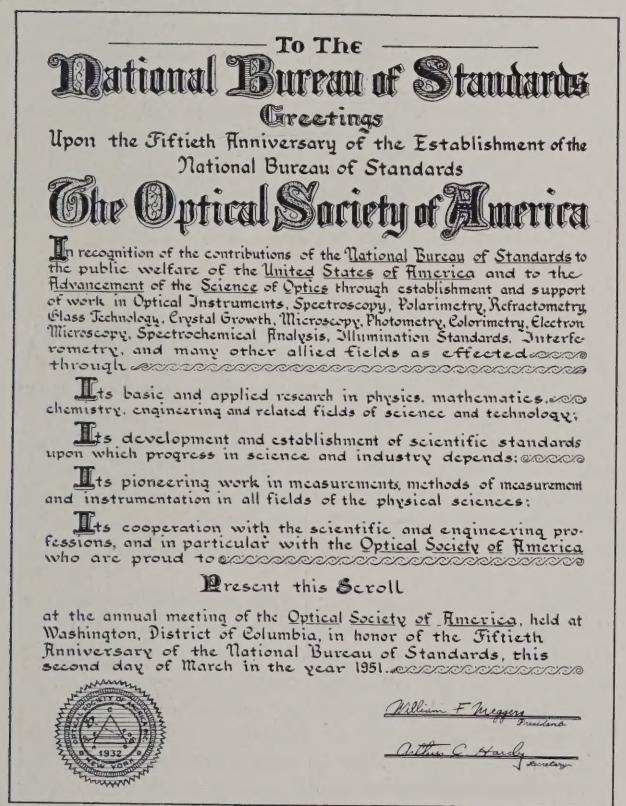
During the meeting the Society paid special tribute to the National Bureau of Standards on the occasion of its fiftieth anniversary. Following the annual banquet, Dr. William Meggers, president of the Optical Society, presented a scroll to the Bureau in recognition of the importance of the Bureau's role in optics. The scroll was accepted by Dr. E. U. Condon, NBS director, on behalf of the Bureau staff.

The Bureau has been active in the field of optics since its founding in 1901, and many of its staff have been active members and officers of the Optical Society. The interrelationship that has existed was shown by Dr. E. C. Crittenden, Emeritus Associate Director of the Bureau and Past President of the Society, in a talk on "Early work in applied optics at the National Bureau of Standards," which will be published in the Journal of the Optical Society. Dr. Condon also spoke on current work at the Bureau.

The 1951 Frederic Ives Medal was presented by the Optical Society to Dr. Brian O'Brien, Director of the Institute of Optics, University of Rochester, for his contribution "to the elucidation of the mechanics of vision and resolution in the retina, as well as other branches of optics and physics". His paper "Vision and resolution in the retina" constituted the first in a Symposium on Vision.

The program for the 3-day meeting also included a symposium on the subject of polarization, and contributed papers on color, polarization, lens properties, microscopy, instrumentation, spectroscopy, and photography. Dr. George Gamow of George Washington University presented, in a popular paper entitled "The first half hour of creation," a scientific conjecture on what happened after light was created.

A tour was made of some of the NBS optical laboratories, where illustrated lectures were given by members of the Bureau staff on the various optical research problems under investigation. The U. S. Naval Observatory, which also held open house for members of the Society, gave demonstrations on current work in progress.



To The
National Bureau of Standards
Greetings
Upon the Fiftieth Anniversary of the Establishment of the
National Bureau of Standards
The Optical Society of America

In recognition of the contributions of the National Bureau of Standards to the public welfare of the United States of America and to the advancement of the Science of Optics through establishment and support of work in Optical Instruments, Spectroscopy, Polarimetry, Refractometry, Glass Technology, Crystal Growth, Microscopy, Photometry, Colorimetry, Electron Microscopy, Spectrochemical Analysis, Illumination Standards, Interferometry, and many other allied fields as effected through

Its basic and applied research in physics, mathematics, chemistry, engineering and related fields of science and technology;

Its development and establishment of scientific standards upon which progress in science and industry depends;

Its pioneering work in measurements, methods of measurement and instrumentation in all fields of the physical sciences;

Its cooperation with the scientific and engineering professions, and in particular with the Optical Society of America who are proud to

Present this Scroll

at the annual meeting of the Optical Society of America, held at Washington, District of Columbia, in honor of the Fiftieth Anniversary of the National Bureau of Standards, this second day of March in the year 1951.

William F. Meggers, President

Arthur C. Hardy, Secretary

Scroll presented to the National Bureau of Standards by the Optical Society of America in honor of the Bureau's Fiftieth Anniversary.

1901 NBS 1951

Semicentennial Meeting Calendar

— June —

14–16 American Chemical Society (Analytical Division)

21–23 American Astronomical Society

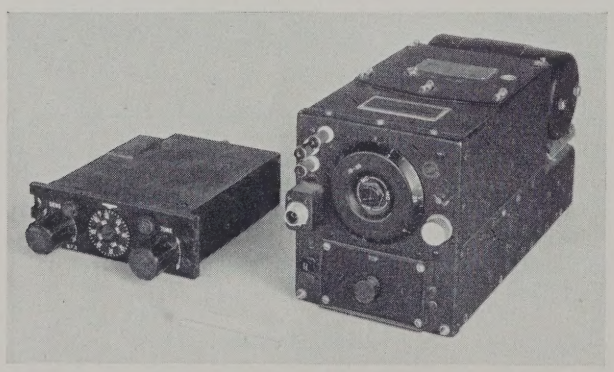
A Subminiature Low-F

A 12-tube subminiature radio receiver for aircraft use, continuously tunable from 190 to 550 kilocycles and utilizing a 135-kilocycle intermediate-frequency amplifier, has been developed by Gustave Shapiro and associates of the National Bureau of Standards electronic miniaturization group. This assembly is the functional equivalent of a World War II unit more than five times as large.

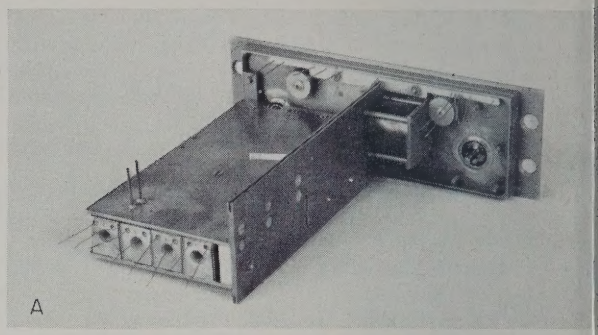
With the use of more and more electronic equipment within the limited space of military planes and tanks, reduction of size has become increasingly important. The Bureau of Aeronautics of the Department of the Navy has therefore initiated at the National Bureau of Standards a broad program for subminiaturization of airborne equipment. Designed and constructed as part of this program, the new low-frequency receiver, in conjunction with a previous high-frequency project (a 60-megacycle, 11-tube intermediate-frequency amplifier assembly), effectively brackets the communication spectrum.

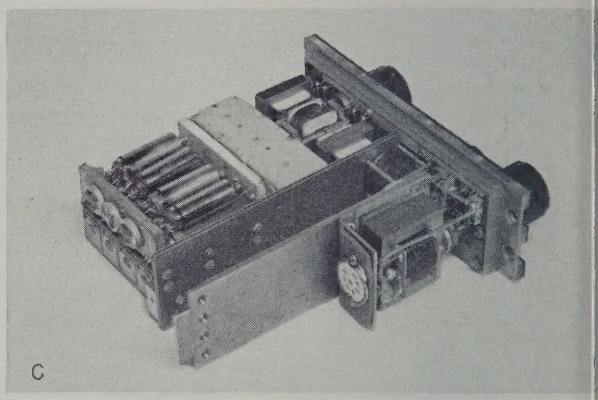
The new equipment, a "radio range" receiver used to keep aircraft on course, occupies about 55 cubic inches, whereas the volume of the original version was approximately 300 cubic inches. Characteristics of the receiver include continuous tuning from 190 to 550 kilocycles, intermediate frequency of 135 kilocycles, a sensitivity of 5 microvolts for 6 decibels signal-to-noise ratio, and a power output of 100 milliwatts. The 12 tubes provide two tuned radio-frequency amplifier stages, a mixer, a local oscillator, two 135-kilocycle intermediate-frequency amplifier stages with a bandwidth of about 2 kilocycles, a diode detector, an a-v-c diode, a beat-frequency oscillator, an audio amplifier stage, and a push-pull-parallel power output stage. All stages operate with 26 volts direct-current on heaters, screens, and plates. Under these conditions of operation, four subminiature audio power output tubes are required for adequate power output.

Unusual design problems were presented by the need for hermetic sealing and the high operating temperatures resulting from the very compact construction. Some of the noteworthy features of the equipment are outlined below.



The new subminiature low-frequency radio receiver (left), developed at the National Bureau of Standards, is the functional equivalent of the World War II airborne unit on the right. Designed and constructed as part of the Navy Bureau of Aeronautics' program of miniaturization of airborne electronic equipment, the diminutive receiver, approximately 55 cubic inches in volume, is less than one-fifth the size of the earlier unit.





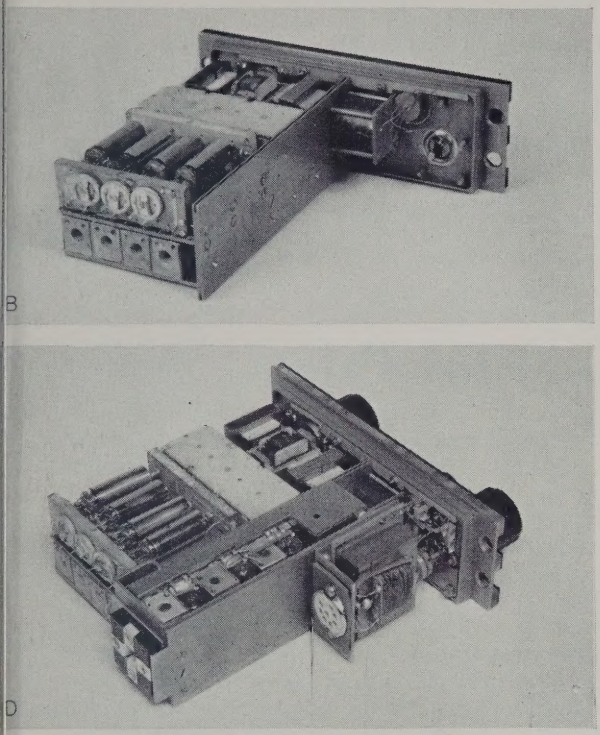
The subminiature low-frequency radio receiver, recei Navy Bureau of Aeronautics, is made up of a number cal tuning assembly and radio-frequency inductors in blies have been added. C: The output transformer, place. D: With the addition of the intermediate-fre is ready for encasement and hermetic sealing in nitro output tube assembly plugs into a set-back outside the

To facilitate mass production, seven detachable subassemblies, each of which can be built independently, are employed in the receiver. This also permits somewhat easier servicing. The subassemblies are fastened to one another and to the front panel, which takes the place of a chassis.

Printed circuits are used to a considerable extent. They are of value both in conserving space and for economical mass production. The wiring is "printed" on steatite or silicone-impregnated fiber-glass.

Hermetic sealing of the entire unit affords protection against moisture and contamination. It also permits elimination of protective coatings for the individual components, which saves space. A soldered copper band seals the housing to the front panel; this band can be removed for repair purposes with a key of the type used for opening coffee cans. The air in the unit was replaced with nitrogen before sealing to prevent

quency Radio Receiver



veloped by the National Bureau of Standards for the ssemblies. A: Back-of-panel view showing mechani- B: Radio-frequency amplifier and power-filter assem- iometer, switch, and associated hardware are now in assembly, and the input-output connector, the receiver o simplify heat and replacement problems, the audio ase.

any possibility of oxidation.

The bushings of the two shafts projecting from the front panel for control purposes also had to be hermetically sealed, and this presented a serious problem. The solution finally devised made use of commercially available rotary seals of the "wobbling-bellows" type. As these were too large to be enclosed in the unit, they were housed in the control knobs, which must be of conventional size for easy manipulation, particularly with gloves.

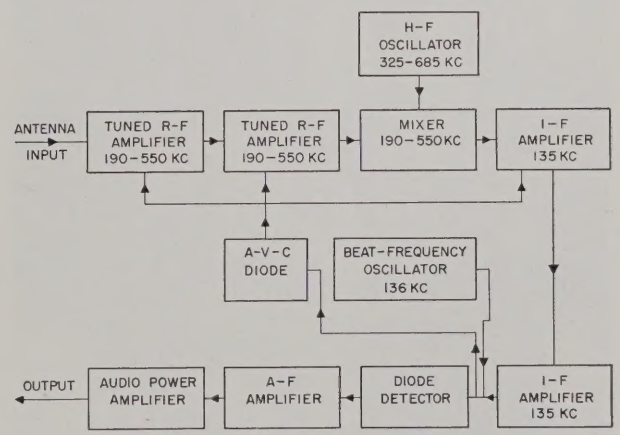
The tuning of the receiver over its wide operating frequency range was a difficult engineering problem. A straight-line tuning characteristic (frequency proportional to control angle) was required, and this could best be attained in the limited space allowable by the use of a variable-pitch screw to drive the slugs in and out of the radio-frequency coils. These screws were readily produced on a standard lathe fitted with a special linear cam attachment designed by Robert O. Stone of the NBS staff. The tuning slugs are made of the newly developed ferrite base materials, more stable at high temperatures than powdered-iron cores. It was expected that production control of these new materials might present a difficulty; mechanical means were therefore provided in the tuner to compensate for possible nonuniformity of core material.

The intermediate-frequency transformers have an over-all size of ½ by ½ by 1⅜ inches. They are double-tuned and use permeability-tuned inductors of about 2.8 millihenries which have Q's of 70 at 135 kilocycles. The resonating capacitors are washer-shaped and mounted in the ends of the transformers. The radio-frequency coil structures resemble those of the intermediate-frequency transformers so that similar parts may be used in both.

High-temperature capacitors of the tantalum electrolytic type are used for the large-capacity applications. Glass dielectric bypass capacitors are also employed. Both steatite and silicone-impregnated fibre glass serve as insulating materials. The audio-frequency transformers (two are needed) and chokes (two line-hash filter-chokes are required) employ high-temperature insulating materials and ceramic-insulated wire, and are impregnated with silicone varnish.

Panel controls involved a design problem: the small size of the panel (5¾ by 1⅞ inches) and the need for hermetic seals made it undesirable to have more than two external controls. Since one of these was required for tuning, the other had to fill the three distinct functions of gain control, power on-off switch, and beat-frequency-oscillator on-off switch. All these latter functions are performed by a special compact switch, designed to be produced entirely by stamping operations.

The specially designed miniature gain control uses a high-temperature adhesive-tape resistor, also developed by the National Bureau of Standards. The tape



Block diagram of the new subminiature low-frequency receiver developed by the National Bureau of Standards for the Navy Bureau of Aeronautics. Although notable compactness is achieved through the use of subminiature components and techniques, the superheterodyne circuit is conventional. Twelve subminiature tubes are used, four of which are required for the audio output stage to secure adequate output with the 26-volt high-voltage supply.

is applied around a small glass cylinder, $\frac{3}{16}$ inch in length and $\frac{1}{2}$ inch in diameter, on which 120 axial lines of silver paint have been deposited to form commutator segments. A precious-metal brush makes contact with the projecting ends of these silver lines.

Aside from its inherent usefulness as an ultra compact piece of airborne communication equipment, the new range receiver has also served as the focal point for the development of several novel components and fabrication techniques. These components, engineered to meet the rigorous size and temperature requirements of subminiature equipment, may well afford superior permanence and reliability when used in equipment of more conventional and less compact design.

NOTE. *The following references include technical details of the earlier work on intermediate-frequency amplifiers:*

Subminiaturization of intermediate-frequency amplifiers, *NBS Technical News Bulletin* **33,** *46 (April 1949).*

Electronic miniaturization, *OTS Report No. PB–100949, 189 pp., $4.75;* **Printed circuits,** *PB–100950, 99 pp., $1.75. Available only from the Office of Technical Services, Department of Commerce, Washington 25, D. C., at the prices indicated.*

New techniques for electronic miniaturization, *by R. L. Henry, R. K. F. Seal, and G. Shapiro, Proc. IRE* **38,** *10 (1950).*

Subminiaturization techniques, *by G. Shapiro. Chapter in Advances in Electronics, volume* **3,** *1951 (Academic Press Inc., New York, N. Y.).*

The Federal Color Card for Paint

Adoption by the Federal Government of a uniform means of indicating paint colors culminates several years of cooperative effort by the National Bureau of Standards and the Federal Specifications Board. The new Federal Specification (see Note), better known as the Federal Color Card for Paints, reduces the more than 600 paint colors formerly used by the Government to 187 by eliminating unimportant variations of different shades.

The new Federal Color Card for Paint consists of actual color spots in a convenient loose-leaf binder. Paul T. Howard of the NBS staff is selecting a color for reference in the procurement of paint.

The various branches of the United States Government collectively form the largest single purchaser of paint in the world. The color card, which consists of actual spots of the colors deposited on charts in a loose-leaf binder, is expected to contribute materially to governmental purchasing economies; paint suppliers will be able to supply paint more quickly and economically, and the various agencies will no longer have the trouble and expense of maintaining their own color standards for distribution to prospective bidders.

Preparation of this Federal Specification was guided by the Federal Specifications Board's Technical Committee on Paint, Varnish, Lacquer, and Related Materials under the chairmanship of E. F. Hickson (retired chief of the NBS paint laboratory). The National Bureau of Standards assisted in its development in many ways. H. J. Keegan of the NBS Photometry and Colorimetry Section served as technical advisor on color, prepared the text, arranged and numbered the color samples, and acted as liaison in most of the development phases. Mr. Keegan and Dr. D. B. Judd of the same section, in cooperation with the Navy Bureau of Supplies and Accounts, prepared those parts of the printing contract relating to color, and acted as referees in adjustments of the color matches submitted by the printer. Paul T. Howard, chemist in the NBS Organic Coatings Section and at present chairman of the Technical Committee, served as one of three members of the group responsible for the inspection and acceptance of the color card.

Many of the paint spots in the new Federal Color Card for Paints have appeared previously in the U. S. Army Specification No. 3–1, Color Card Supplement. In addition to these colors used by the Department of the Army, the specification includes paint colors used by the Department of the Navy, the Department of the Air Force, the U. S. Maritime Commission, the Veterans Administration, the Panama Canal, the Post Office Department, the Department of Agriculture, the Department of Commerce, the Department of Interior, the Department of Justice, the Public Buildings Administration, the Civil Aeronautics Administration, the

U. S. Coast Guard, the U. S. Marine Corps, and other Government departments and agencies. By common agreement among these Government activities, near replicas of many colors have been avoided and a consequent reduction effected in the total number of colors included.

The paint color spots covered by the specification provide a simple, practical means of indicating paint colors. The specification describes a method for the rapid visual comparisons of colors, to check the conformity of paint for the supplier, and in a supplement, will give fundamental colorimetric data for correlation with systems similarly specified.

Classification and Numbering System

Each spot consists of an area 2⅝ by 1¾ inches, coated with a pigmented lacquer. The spots are classified in three main groups depending upon the gloss of the surface finish: These are glossy colors, semiglossy colors, and lusterless (or flat) colors. Each group is further classified according to the hue name, presented in the order brown, red, orange, yellow, green, blue, gray, and miscellaneous (including black and white). For a particular color group, the colors are arranged, when possible, in the order of dark to light. The spots were reproduced by the McCorquodale color process, in which all spots of lacquer are simultaneously deposited directly on the loose-leaf sheets making up the specification.

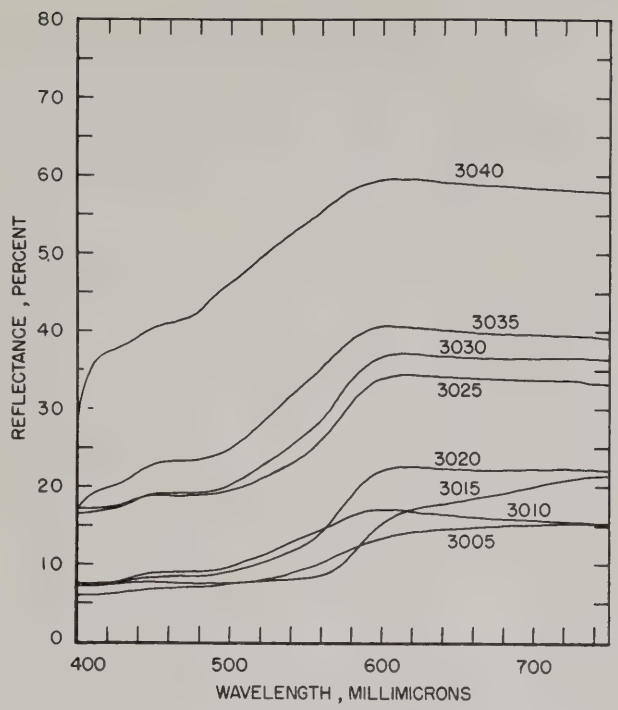
The numbering system used for the color spots is based on the arbitrary assignment of numerals in multiples of 100 to each of the eight color classification groups. Open numbers have been left between each two adjacent color spots in order to permit the insertion of additional spots without destroying the progression of spots from dark to light.

Classification and numbering of paint color spots

Color classification	Glossy	Semiglossy	Lusterless
Brown	1000	2000	3000
Red	1100	2100	3100
Orange	1200	2200	3200
Yellow	1300	2300	3300
Green	1400	2400	3400
Blue	1500	2500	3500
Gray	1600	2600	3600
Miscellaneous	1700	2700	3700

Colorimetric Analysis and Permanence Study

Most material working standards for color are specified on a fundamental basis, using the present-day methods for the engineering description and specification of color. For this reason a spectrophotometric and colorimetric analysis of a master set of these paint color spots is being made by the Photometry and Colorimetry Section of the National Bureau of Standards. The paint spots thus expressed in the fundamental terms of the ICI standard observer and coordinate system may be correlated with material working standards in systems of color, collections of color samples, or specifications for color. This fundamental analysis will also serve as a guard against "color drift" in any reissue of the paint spots.



Curves traced by a recording spectrophotometer indicate the spectral reflectances of the eight lusterless brown samples in the new Federal Color Card for Paints. The numbers identify the curve for each of the samples. Calibration curves appearing on the original trace have been eliminated for simplicity.

In addition to the fundamental colorimetric specification of a collection of color samples, it is often convenient to have available the more popular but usually less exact specification of samples in terms of the Munsell System of Color. The Bureau will therefore define a master set of color spots in terms of the Munsell System of Color both by the method of visual comparison and by the method of spectrophotometric analysis. The "ISCC–NBS (Inter-Society Color Council—National Bureau of Standards) system" for naming the color can then be utilized.

Because there are three general classifications of the specular components of the light reflected from the surface finishes of the paint spots, gloss measurements will also be made of a master set of these color spots for an initial record. Thus, with initial data on the master set based on spectrophotometry, colorimetry, and glossimetry, subsequent redetermination may be made to study the permanence of the color spots.

The color tolerance used in developing the new specification was based on the *NBS Unit of Color Difference*

defined by equation 13 of NBS Circular C429 (Photoelectric tristimulus colorimetry with three filters, by Richard S. Hunter, July 30, 1942). The NBS unit of color difference is intended to be so small that color differences of less than one unit will be perceptually unimportant in most commercial transactions. This value is about three or four times the smallest color difference perceptible with certainty under the best conditions of observation by a trained inspector.

NOTE: *The new color card is identified as Federal Specification TT–C–595, Colors: (for) ready-mixed paints. For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., Price $4.50.*

SEAC Demonstrates High Reliability

Large-scale electronic computers have received widespread attention since the war, but only a very few have reached the stage of regular productive computational activity. Since its dedication in June 1950, the National Bureau of Standards Eastern Automatic Computer—SEAC—has solved a large number of important problems (see table 1 for some examples of unclassified problems), and has demonstrated a remarkable reliability in operation (tables 2 and 3). Until now, little or no reliable information has been available on any postwar high-speed electronic computer in regular use. The SEAC reliability data are based on actual operation over a period of 3 months, October through December 1950.

SEAC was developed and constructed by the NBS staff under the sponsorship of the Department of the Air Force to provide a high-speed computing service for Air Force Project SCOOP (Scientific Computation of Optimum Programs), a pioneer effort in the application of mathematical techniques to large-scale problems of military procurement and administration. SEAC is also available for solving other important problems of general and special scientific and engineering interest.

Despite its intricate construction, SEAC has proved remarkably trouble-free in operation. R. J. Slutz (left) inspects SEAC's input medium, a perforated paper tape, while S. N. Alexander examines a problem solution being automatically printed by the machine's output unit.

The new electronic computers are highly intricate, with tremendous numbers of components and connections. The reliability demanded of parts and wiring in such machines is inordinately high. SEAC contains some 11,000 germanium diodes, 800 vacuum tubes, 500 pulse transformers, and 100,000 soldered connections. Failure even for a millionth of a second of a single one of these myriad connections and components will result in computer misfunction. These factors impose extremely severe design, construction, and maintenance requirements.

SEAC's operations were scheduled on a 24-hours-a-

TABLE 1.—*Some problems run on SEAC through December 1950*

Problem	Total hours on the machine	Brief description
Linear programming, Office of the Air Comptroller.	525	Solution of large systems of linear algebraic equations pertaining to program planning for the Air Force.
Number theoretical problems.	200	Computation of factorization tables, tables of primes, primitive roots of primes, diophantine equations, and haupt exponents.
Circuit design.....	72	Study of the starting transient in a class C oscillator.
Subsampling design, Census.	68	Determination of sample sizes corresponding to minimum variance in a census, using sampling methods.
Relative abundance of elements.	48	Solution of a 27th order system of ordinary differential equations relating to the neutron capture theory of the formation of the elements in the universe.
Heat transfer.....	45	Transfer of heat in an atmosphere of varying density.
Social security problem.	19	Study and demonstration of sorting and tabulating routines.
Van der Pol's equation.	17	Study of a second order nonlinear differential equation describing an oscillator circuit with a nonlinear element.
Analysis of sampling plans	9	Generation of random samples from a normal probability distribution, and application of acceptance criteria to them.
Nonlinear spring.....	7	Study of a simple harmonic oscillator with nonlinear restoring force.
Gamma-ray penetration.	5	Solution of a chain of Volterra integral equations relating to gamma-ray penetration in materials.
Optical ray tracing....	1	Calculation of the path of skew rays through a system of lenses.
Analysis of crystal structure.	½	Calculation of electron density in unit cell of a crystal from observed "structure factors".

TABLE 2.—*Utilization of time allotted to problem solution on SEAC in the last 3 months of 1950*

Week of—	Total hours assigned to problem solution	"Good" hours			"Down" hours			Good portion of total problem time
		On problem solutions	On coding checks	In order but idle	Debugging	Machine error	Out of order idle	
								Percent
Oct. 1	76	30	11	0	[a]68	[a]30	[a]22	54
Oct. 8	76	11	4	4	[a]54	[a]28	[a]32	25
Oct. 15	79	30	28	2	10	8	1	78
Oct. 22	74	56	9	1	0	8	0	89
Oct. 29	98	59	12	2	5	19	1	75
Nov. 5	76	35	5	0	21	15	0	53
Nov. 12	76	44	13	0	6	13	0	76
Nov. 19	64	25	25	4	3	7	0	84
Nov. 26	82	34	18	7	3	20	0	72
Dec. 3	77	55	10	2	6	4	0	87
Dec. 10	86	52	6	6	7	12	3	74
Dec. 17	58	44	3	3	0	8	0	86
Dec. 24	76	41	29	3	0	3	0	96

[a] These figures include engineering time as well as problem-solution time.

day, 7-days-a-week basis during October, November, and December 1950. In general, of each week's 168 hours, 16 were reserved for preventive maintenance, while 76 hours were allocated to engineering development and testing of new computer equipment. The remaining 76 hours were devoted to SEAC's primary mission, the solution of problems.

For the entire 3 months, the "good" time was 76 percent of the total time assigned to problem solution. Week by week during the period, the reliability trend was irregularly upward, with the figure reaching a high of 96 percent for the last week (table 2).

The "good" portion of the time dedicated to problem solution was that in which (1) either problem solutions or coding checks were turned out correctly by the machine, or (2) the machine was in good operating condition but idle. The machine was actually solving problems correctly during more than half (52%) of the time assigned to problem solution; coding checks took 17 percent of the time; and during only about 3 percent of assigned time was the machine in order but idle.

"Down" time—28 percent of the total hours allotted to problem solution—was a combination of (1) time lost because of machine misfunction during problem solution (including the time used for rerunning problems), (2) time lost while machine difficulties were being diagnosed and remedied, and (3) time during which the machine was out of order and idle.

"Good" time was a similarly high proportion—76 percent—of the total time assigned to engineering work during the 3-month period (table 3). "Good" time, in this case, was that in which there was no difficulty with any machine unit that had previously been put into regular operation.

SEAC was producing correct solutions during some 516 hours in the last 3 months of 1950. Since the machine can add or subtract pairs of 14-digit numbers up to 5,000 times per second, and multiply or divide them 330 times per second, an enormous number of individual mathematical operations are performed in each functioning hour. The great speed of the giant computer makes feasible the solution of lengthy problems that would be quite impracticable to attempt by less advanced methods. Because of its speed, such a computer, even if "down" a considerable percentage of the time may have a much higher output of useful results than the best prewar mechanical computer working full time.

TABLE 3.—*Utilization of time allotted to engineering work on SEAC in the last 3 months of 1950*

Week of	Total hours assigned to engineering work	"Good" hours		"Down" hours			Good portion of total engineering time
		Engineering time	In order but idle	Debugging	Machine error	Out of order idle	
							Percent
Oct. 1	.....	0	0	.....	.....	.....	.....
Oct. 8	.....	20	0	.....	.....	.....	.....
Oct. 15	69	20	1	30	0	18	30
Oct. 22	74	43	9	9	4	9	70
Oct. 29	55	38	3	8	0	6	75
Nov. 5	70	50	1	19	0	0	74
Nov. 12	67	24	15	23	5	0	58
Nov. 19	62	55	2	0	4	1	92
Nov. 26	57	57	0	0	0	0	100
Dec. 3	57	56	1	0	0	0	100
Dec. 10	43	42	1	0	0	0	100
Dec. 17	54	40	7	7	0	0	87
Dec. 24	20	12	2	6	0	0	70

In the interest of both economy and reliability, SEAC uses far fewer vacuum tubes than did the first computers of this type built during World War II. ENIAC—the pioneer in this field—contained 18,000 vacuum tubes. SEAC, on the other hand, has only 800 tubes. This does not mean, however, that computing capacity has been sacrificed, or that SEAC is intrinsically a simpler machine. In SEAC, vacuum tubes are used only for amplification; 11,000 germanium diodes are used in preference to tubes for computing and switching functions. Germanium diodes are longer-lived and, since they have no filaments or heaters, reduce the amount of wiring and eliminate a major source of heat.

SEAC has disposed of a wide range of important problems since its unveiling (table 1). Air Force problems of a production-scheduling nature have received the greater part of the computer's attention. These problems have been reduced to the solution of large systems of linear algebraic equations. Other tasks attacked by SEAC concerned such varied matters as electronic circuit design, optical lense calculations, relative abundance of chemical elements, complex mathematical functions, and sorting and tabulating studies for the Social Security Administration and the Bureau of the Census.

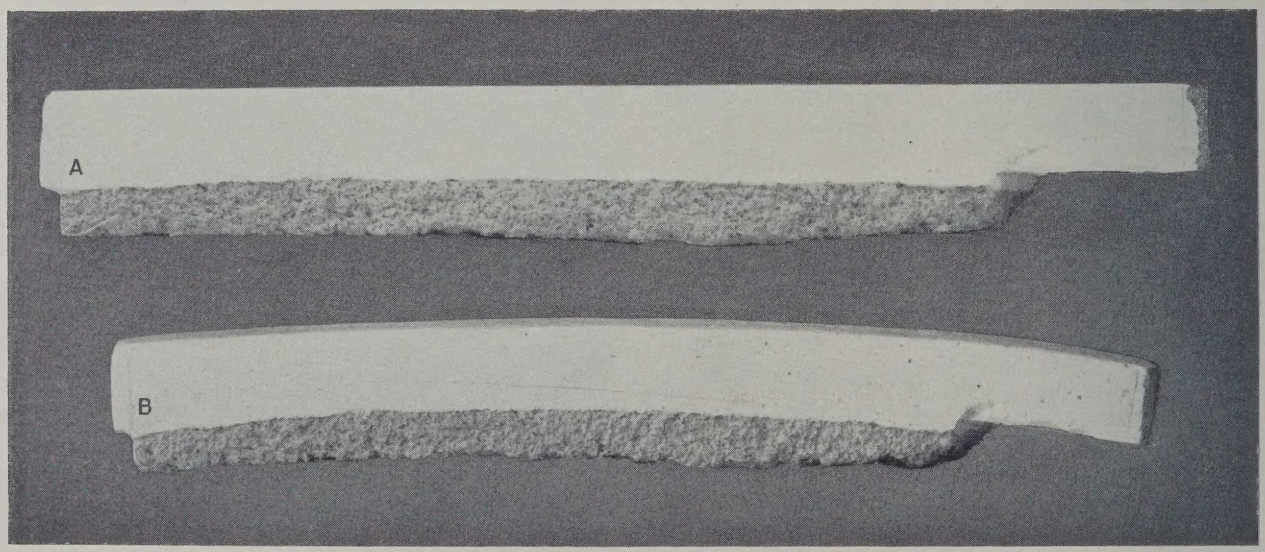
Now pressing for attention are many other problems, important to scientific progress and to the national welfare, which advanced electronic computers are uniquely qualified to solve. Maximum utilization of the potentialities of these computers—still very few in number—is important. In the case of SEAC, a notably high reliability has been attained in actual service in the rapid solution of important problems.

See also NBS Technical News Bulletin **34**, *121 (September 1950).*

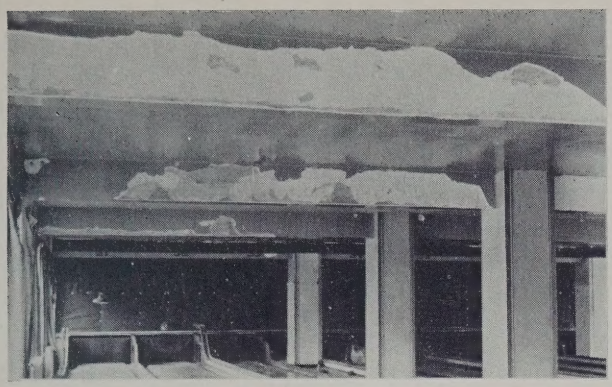
Plaster Failures Resolved

Hydrated limes for white-coat finishing plasters having improved structural qualities are now being manufactured as a result of research carried out at this Bureau. The studies were prompted by widespread blister-type plaster failures, which exact an annual toll of millions of dollars, and revealed that the failures were caused by the expansion of one of the components of the partially hydrated "dolomitic" lime used extensively throughout the country for preparing finishing plaster. This component—unhydrated magnesia—was found to be characteristic of a large percentage of such limes. Methods for treating the lime and decreasing the unhydrated magnesia have been developed by the Bureau in cooperation with industry and have already been introduced into commercial production. Plasters made from lime that is produced in this way are not subject to the blister type of failure. The American Society for Testing Materials (ASTM), the American Standards Association, and the Federal Government have now adopted new specifications for finishing lime that are based on these findings.

The cost to the Nation of continual repair of plaster surfaces is difficult to appraise, but it is known to be high. The repair of just four Government buildings alone has cost over $158,000. In still another Federal building, $200,000 has been spent in 8 years for such repairs. Private office buildings, hotels, and dwellings encounter similar difficulties. In fact, many office build-



A cross section (A) of white-coat plaster adhering to a sanded-gypsum-plaster base coat that had been applied over a concrete beam. After autoclaving (B) the expansion and bending of the white coat caused a deformation of the base coat, clearly showing the direction of the forces set up.



These failures along sides of concrete beams over a bowling alley were confined almost entirely to loosening of the bond between successive layers of white coat or between the white coat and the gypsum bond plaster.

ings and hotels spend from 5 to 10 thousand dollars each year as a result of plaster failures.

Following the discovery of the cause, a comprehensive research program was initiated at the National Bureau of Standards, and a method was developed for overcoming the expansion difficulties for finishing plasters. Lime is ordinarily slaked, or hydrated, before use. During this process water reacts with the constituents of the lime. Because of its convenience, plasterers welcomed the use of dry hydrated dolomitic lime prepared at the lime plant. However, the demand for a dry powdered product led, in the case of the older normal manufacturing process, to the result that a large part of the less easily hydrated constituent, magnesium oxide, remains unhydrated. Even after the plaster containing a normally hydrated dolomitic lime has been applied, the unhydrated magnesia (magnesium oxide) slowly takes up water from the air: this process is accompanied by an increase in volume. Eventually, usually from 5 to 20 years after the white coat is applied, the plaster often expands so much that it bulges, cracks, or even falls from the surface.

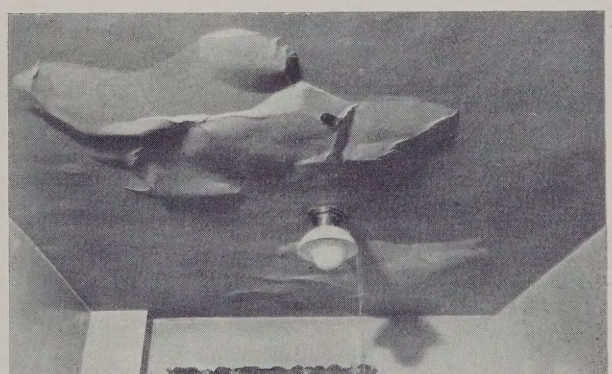
The new method usually involves use of a large autoclave in which steam at elevated temperature and pressure effects a chemical bonding of water with the components of the lime. The resulting compounds are stable with respect to water and consequently do not react with it further, precluding volume expansion and thus eliminating plaster failure. The Bureau carried the investigation through the laboratory and assisted in early stage pilot-plant experiments. The results pointed the way to commercial application of the method, and manufacturers are now producing a hydrated dolomitic lime with the magnesia so well hydrated that harmful expansion does not take place. The ASTM has designated this new lime "Type S", and the older (normally hydrated), "Type N" hydrated dolomitic lime.

Because the chemical composition alone does not always provide a suitable technical criterion for the soundness of lime, the National Bureau of Standards has also developed suitable performance tests. As there is no satisfactory test procedure for ascertaining volume-change characteristics of hydrated lime by itself, it was necessary to gage the sample with some cementitious material having hydraulic properties. Portland cement was therefore used in the preparation of test specimens for autoclaving. The linear expansion caused by the autoclaving of cement-lime bars thus provided a measure of the expansive properties of the limes from which they were made. Eighty commercial limes were subjected to the autoclave treatment and to other tests for determining the effect of such variables as the proportions of cement to lime and the use of different cements in the bars.

From the techniques developed and the data obtained, details of the test procedure have been worked out. It was proposed that hydrated lime be tested in the proportion of 1 part cement to 1 part lime (by weight); that the cement used have an expansion between 0.05 and 0.15 percent; that the autoclaving be done at 295 pounds per square inch gage pressure for 1 hour according to a controlled schedule; and, finally, that the difference between the expansion of the cement-lime bar and that of the neat-cement bar be not more than 1 percent.

A limit of 1.0 percent expansion should afford adequate protection for the consumer and not work an undue hardship on the producer. Furthermore, an accelerated performance test should be preferable to limiting the chemical composition. It is believed therefore that a limit of 1 percent (net) on the autoclave expansion of bars made in the proportion of 1:1 (cement : lime by weight) is better than a limit on the percentage of unhydrated oxides, which was tentatively set at 8 percent in a proposed amendment to the Federal specification when the NBS results were first made known. An autoclave test for soundness, with the 1-percent limit, is being submitted to the Federal Specifications Board for a proposed revision of the Federal Specification for hydrated lime intended for structural purposes (SS–L–351).

Until such a soundness test, or modification thereof, is adopted in specifications, the Bureau recommends that the buyer insist upon Type S hydrated lime that contains not more than 8 percent of unhydrated oxides



A kitchen ceiling in an apartment house reveals pronounced bulging in the white coat caused by expansion.

(calculated on the received basis). A statement of the unhydrated oxide content is generally printed on bags containing this new type of lime.

Not only are plaster failures costly, but they occasionally represent a hazard to public safety. The recent collapse of 12½ tons of tile, plaster, and metal, comprising the ceiling of a high school swimming pool in Rochester, N. Y., suggests this danger. The failure, which occurred while the pool was empty, resulted from the expansion and upward buckling attending the slow hydration of the magnesia in the body of the plaster used for the arched hung ceiling. The buckling removed the ceiling load from some of the rods carrying the structure and overtaxed the strength of those that remained. Failure of the remaining overloaded rods precipitated collapse of the entire ceiling.

The importance of the NBS plaster-failure investigation to the lime manufacturer, the building industry, and the consumer is self-evident. The comprehensive report on this subject serves two purposes. It gives, first, the results of the investigation of plaster failures characterized by the formation of blisters or bulges in the finish surface of plaster, and then explains—for the benefit of the architect, engineer, plastering contractor, plasterer, and others concerned with plastering—the precautions that should be exercised in new building to prevent such failures.

For further technical details, see National Bureau of Standards Building Materials and Structures Report BMS121, Investigation of failures of white coat plaster, by L. S. Wells, W. F. Clarke, E. S. Newman, and D. L. Bishop. For further details pertaining to the development of an autoclave soundness test, see Expansive characteristics of hydrated limes and the development of an autoclave test for soundness, by L. S. Wells, W. F. Clarke, and E. M. Levin, J. Research NBS 41, 179 (1948) RP1917. For methods of calculating the percentage of unhydrated magnesia, see Misc. Pub. M196, Nomograms for obtaining the compound composition of hydrated limes from the oxide analysis, by Ernest M. Levin.

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U. S. GOVERNMENT PRINTING OFFICE: 1951